X-ray emission from the remarkable A-type star HR 8799
(Research Note)

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ABSTRACT

Aims. A strong decline of magnetic activity towards hotter stars occurs in the regime of mid/late A-type stars due to the vanishing of the outer convection zone. X-ray emission is an important diagnostic of studying possible activity in intermediate-mass stars.
Methods. We present a Chandra observation of the exceptional planet bearing A5 V star HR 8799, more precisely classified as a kA5 hF0 mA5 star and search for intrinsic X-ray emission.
Results. We clearly detect HR 8799 at soft X-ray energies with the ACIS-S detector in a 10 ks exposure; minor X-ray brightness variability is present during the observation. The coronal plasma is described well by a model with a temperature of around 3 MK and an X-ray luminosity of about $L_X = 1.3 \times 10^{28}$ erg/s in the $0.2 - 2.0$ keV band, corresponding to an activity level of log $L_X/L_{bol} \approx -6.2$. Altogether, these findings point to a rather weakly active and given a RASS detection, long-term stable X-ray emitting star.
Conclusions. The X-ray emission from HR 8799 resembles those of a late A/early F-type stars, in agreement with its classification from hydrogen lines and effective temperature determination and thus resolving the apparent discrepancy with the standard picture of magnetic activity that predicts mid A-type stars to be virtually X-ray dark.

Key words. Stars: activity – Stars: coronae – Stars: individual HR 8799 – X-rays: stars

1. Introduction

The star HR 8799 (V 342 Peg, HD 218396) is usually classified as spectral type A5 V, located at a distance of 39.9 pc and has a visible magnitude of V = 5.96 mag with B-V = 0.23. It is an exceptional and so far unique star, it is a λ Bootis, γ Doradus and Vega-like at the same time. γ Doradus stars are a class of pulsating stars that typically reside at the cool edge of the Cepheid instability strip with spectral types mid-A to mid-F. HR 8799 was linked to the class of λ Bootis stars by Gray & Kaye (1999); λ Bootis stars are chemically peculiar, metal-poor (in particular the Fe-peak element,s but with the exception of C, N, O) A-type stars that do not exhibit ordered large-scale magnetic fields as observed in Ap stars (Bohlender & Landstreet 1990). Gray & Kaye (1999) derived a metallicity of [M/H] = -0.47 for HR 8799 and determined its stellar parameters to $M = 1.47 \pm 0.30 \, M_\odot$, $R = 1.34 \pm 0.05 \, R_\odot$, $L = 4.92 \pm 0.41 \, L_\odot$ (1.9×10^{34} erg/s) and $T_{eff} = 7430 \pm 75$ K. They assigned it the spectral type kA5 hF0 mA5 v λ Boo to indicate that HR 8799 is a mild λ Bootis star that exhibits the A5 standard in the CaII K line as well as in other metallic lines, however the hydrogen profiles (and thus effective temperature) are in better agreement with the F0 standard. The λ Bootis phenomenon is thought to be caused by the accretion of metal depleted material, i.e. external processes, in line with the finding that HR 8799 is also a 'Vega-like' star that shows a far-IR excess flux at 60 μm from circumstellar dust in IRAS data (Sadakane & Nishida 1986). Additionally, there is strong evidence for a dusty debris disk from IR observations (Zuckerman & Song 2004).

Recently, HR 8799 gained even more interest when multiple orbiting planets were detected by direct imaging (Marois et al. 2008). The three planets are located at distances of several tens (24, 38, 68) AU and have masses around 10 M_J each. The authors

derived an age of about 60 Myr (30 – 150 Myr) from various lines of evidence, thus HR 8799 is likely relatively young. While stellar radiation, especially energetic ones like UV and X-rays, influences the evolution of circumstellar material and thus planet formation, the planets themselves are likely not important in the generation of X-ray emission in such stellar systems. Although its $V \sin i = 38 \pm 2$ km/s (Kaye & Strassmeier 1998) is only moderate for an A-type star and the exact orientation of the rotation axis is unknown, astrometric analysis of the detected planetary system suggests a rather low inclination and consequently fast rotating star, e.g. $V_{rot} \gtrsim 100$ (200) km/s for $i \lesssim 20$ (10)°.

Hints for X-ray emission from HR 8799 came from RASS (ROSAT All-Sky-Survey) data via a cross-correlation search between X-ray positions and bright A-type stars (Hünsch et al. 1998). They found that the position of the soft X-ray source 1RXS J230729.0+210802 matches quite well with the one of HR 8799; however, the positional uncertainty and the low number of detected counts (10 photons) prevent a detailed investigation. On the other hand, Kaye & Strassmeier (1998) attributed the chromospheric Ca II K flux of HR 8799 to be of basal origin. From the X-ray point of view HR 8799 is remarkable, since an A5 star should be virtually X-ray dark in the standard paradigm that is valid for main sequence stars. In this scheme X-ray emission is expected from magnetic activity in the regime of 'cool stars' (spectral type around A7 and later) and from wind-shocks in the regime of 'hot stars' (B2 and earlier); intermediate spectral types are virtually X-ray dark. Exceptions are found among young Herbig AeBe stars and peculiar Ap/Bp stars, where fossil magnetic fields are thought to play a mayor role in the generation of X-rays. This picture is well established by X-ray observations with *Einstein* and ROSAT, showing that stellar activity develops in late A-type stars and increases strongly towards cooler stars,

with activity levels being in the range of $\log L_X/L_{bol} = -3 \ldots -7$ (e.g. Schmitt et al. 1985; Schmitt 1997). A recent *XMM-Newton* observation of the fast rotating A7 star Altair confirmed the presence of weak magnetic activity and coronal X-ray emission (Robrade & Schmitt 2009). The vanishing of magnetic activity in mid A-type stars is expected theoretically and confirmed with other activity indicators; e.g. FUSE observations of main sequence stars have shown the disappearance of chromospheric emission lines at effective temperatures above $T_{eff} \approx 8200\,\text{K}$ (Simon et al. 2002).

In this paper we present results from a *Chandra* ACIS-S observation of HR 8799. Our paper is structured as follows: in Sect. 2 we describe the observation and data analysis, in Sect. 3 we present our results and summarize our findings in Sect. 4.

2. Observations and data analysis

The target HR 8799 was observed by *Chandra* with the back-illuminated S3 chip of the ACIS-S detector in August 2009 for about 10 ks (Obs.-ID 10975). We use the standard software package CIAO 4.1 to analyze the data, including the tool 'wavedetect' to derive the source position. Source photons were found in the 0.15 – 2.0 keV energy range, where we detect 137 photons in a 2″ circular region around the position of HR 8799 with an expected background of 0.2 photons as deduced from nearby source-free regions. These photons are denoted as source photons in the following and enable a more detailed study of the X-ray properties of HR 8799, compared to the ROSAT data.

Spectral analysis is done with XSPEC V12.3 (Arnaud 1996) and we require a minimum of 15 counts per spectral bin in our modelling. To model the spectra we use photo-absorbed, multi-temperature APEC models; all abundances are relative to solar values as given by Grevesse & Sauval (1998). We find that no absorption component is required to describe the obtained X-ray spectrum, enforcing interstellar absorption at a level of $N_H = 10^{19} - 10^{20}\,\text{cm}^{-2}$ does not significantly change the results.
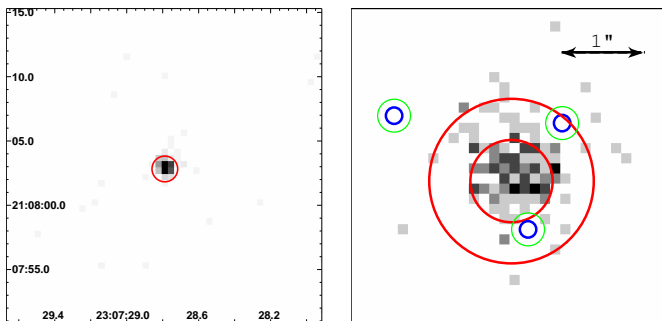

Fig. 1. *Left*: ACIS-S image of HR 8799 and optical position. *Right*: Sub-pixel image with the three planets marked (see text for details).

3. Results

3.1. Images and light curves

In the left panel of Fig. 1 we show the obtained X-ray image of the source and the optical position of HR 8799, denoted by a circle with a 1″ radius, corresponding to ≈ 95% encircled X-ray energy. The right panel shows a zoom-in of the source, the outer circle is the same as in the left panel, whereas the inner half-sized circle corresponds to 65% encircled energy. Additionally,
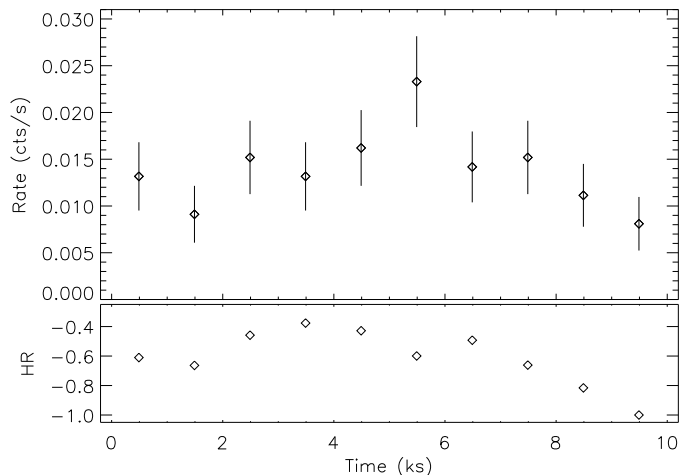

Fig. 2. Light curve and hardness ratio of HR 8799 (1 ks binning).

the planetary positions are marked (small circles with 0.1″ and 0.2″ radius). Only one X-ray source is present in the vicinity; it appears point-source like and its position agrees with an absolute offset of only 0.2″ very well with the optical position of the A-type star HR 8799. No significant excess emission is seen at any of the positions of the detected planets (separations to HR 8799 between 0.6″ and 1.7″) nor at the positions of the substellar companions that were detected as point-source candidates in a coronographic survey performed with NICMOS/HST at distances of 13.7″ and 15.7″ (Lowrance et al. 2005). Possible X-ray emission from any of these objects is at least two orders of magnitude fainter than those from HR 8799. HR 8799 is thought to be a single star and given the accurate source position obtained from the ACIS data we attribute the detected X-ray emission exclusively to the A5 star HR 8799.

Bohlender & Landstreet (1990) put upper limits of a few hundred Gauss on the longitudinal magnetic field component in a sample of λ Bootis stars, not including HR 8799 and ruling out the existence of strong, ordered fields. However, small-scale magnetic fields as expected for a corona that originates from magnetic activity may easily be present. The X-ray emission from HR 8799 implies the presence of a magnetic field on HR 8799, thus λ Bootis stars are not exclusively non-magnetic.

To investigate the X-ray variability of HR 8799, we create a light curve with 1 ks binning from the source photons (Fig. 2, upper panel). The light curve is moderately variable; the count rate changes by up to a factor of about two, however the exact level of the variability is not well constrained. We also studied light curves with shorter time bins of e.g. 100 s, but find no indications for strong short-term variability that would be present for burst-like flares.

We study the origin of the observed variability and search for spectral variations related to the changes in X-ray brightness by determining the respective hardness ratio $HR = (H-S)/(H+S)$ for each time bin, with $S = 0.15 - 0.7$ keV and $H = 0.7 - 2.0$ keV being the respective photon energy bands (see lower panel, Fig. 2). Spectral lines are unresolved in the ACIS spectrum, however the emission below 0.7 keV is dominated by cooler plasma with line peak formation temperatures in the range of 1 – 4 MK, while above 0.7 keV lines from hotter plasma ($\gtrsim 5$ MK) dominate. If enhanced magnetic activity is the origin for the X-ray brightening, one expects a correlation of the X-ray brightness with the hardness of the emission. The error on the individual hardness ratio bins is about ±0.25, but indeed harder emission
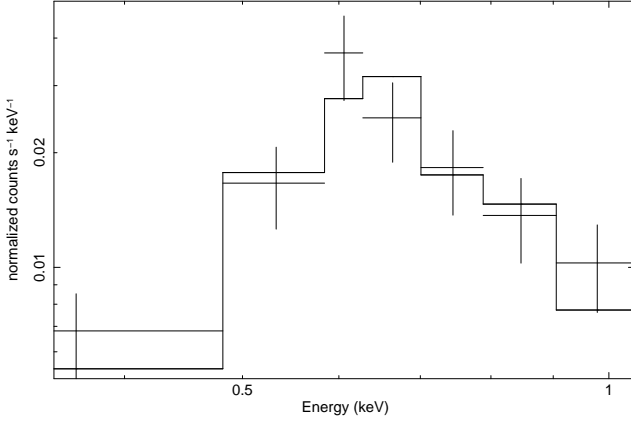
Fig. 3. ACIS-S spectrum of HR 8799 with applied spectral model.

Table 1. Spectral fit results derived from ACIS-S data.

Par.	1-T models		unit
T1	0.26±0.03	0.26±0.03	keV
Abund.	0.33	1.0	solar
EM1	$1.9\pm0.3\times10^{51}$	$6.9\pm1.1\times10^{50}$	cm^{-3}
χ^2_{red}(d.o.f.)	0.83 (5)	1.14 (5)	

3.3. HR 8799 in the context of A-type stars

The activity level as well as the X-ray luminosity of HR 8799 are about an order of magnitude larger than those of magnetically active mid to late A-type stars like Alderamin (α Cep) or Altair (α Aql), both of spectral type A7. These stars have X-ray luminosities of one to a few times 10^{27} erg/s and activity levels of log $L_X/L_{bol} \lesssim -7$. Compared to Altair, the hottest magnetically active star studied in detail at X-ray energies (Robrade & Schmitt 2009), the X-ray surface flux of HR 8799 is by about a factor 20 higher; further the average coronal temperature of HR 8799 is with 3.0 MK slightly higher than those of Altair that is around 2.5 MK, but within the errors this difference is not very significant. This matches the finding that Altair's activity level is with log $L_X/L_{bol} = -7.4$ very low, even when compared to the weakly active stars HR 8799. However, the ultra-fast rotator Altair is already around its maximum possible activity level and a significant spin-up would disrupt the star. Consequently, the dynamo mechanism in HR 8799 needs to be more efficient than that in Altair. The efficiency of a solar-type dynamo is proportional to the inverse square of the Rossby-Number (Ro = P/τ_c), with P denoting the rotational period and τ_c the convective turnover time. A significantly shorter rotation period for HR 8799 is ruled out when considering stellar dimensions, $V\sin i$ and geometry; thus a deeper convection zone would provide a natural explanation for the required efficiency.

This is in line with the finding that for the spectral classification as an A5 star the determined $T_{eff} \approx 7400$ K from Gray & Kaye (1999) is rather low. Thus one might assume that its internal structure is better described by a F0 star. In this case the outer convection zone would easily provide sufficient dynamo action to generate the observed X-ray emission from magnetic activity. The still rather low activity level of log $L_X/L_{bol} \approx -6.1$ (active late-type stars have log $L_X/L_{bol} \approx -3$) that is required to generate the observed X-ray emission from HR 8799 is easily achieved in this case. Further, as it is also the case for Altair, the surface of HR 8799 is not necessarily homogeneous and specific surface areas like an equatorial bulge may contribute predominantly to the X-ray emission

The activity level as well as the the coronal properties support the hypothesis that the often used 'metallic' classification as A5 star does not reflect the properties that underly magnetic activity phenomena. From the X-ray point of view, HR 8799 resembles much more an late A or early F-type star. This is in line with its classification based on hydrogen lines and its effective temperature derived from spectral modelling. Consequently, the X-ray emission from HR 8799 appears rather natural. Sufficient sensitive searches with other indicators should also reveal signs of magnetic activity phenomena on this remarkable star.

is observed during X-ray brighter phases. A Spearman's rank correlation gives a chance probability of 0.07 that the correlation is due to a statistical fluctuation for the used ten time bins. Thus variable magnetic activity is the likely cause for the observed moderate X-ray brightness variability, whereas more extreme flaring events as observed on active stars are not present on HR 8799 during our observation.

3.2. Spectral analysis

We determine the global spectral properties of HR 8799 by fitting the ACIS spectrum with multi-temperature spectral models. The metallicity of the coronal plasma can only be poorly constrained with the existing data and was fixed. Using the photospheric value of HR 8799, determined to 0.33 solar abundances (Gray & Kaye 1999), already a one temperature model is sufficient to describe the data. The corona therefore also seems to exhibit the photospheric sub-solar composition, but Adopting solar abundances results in correspondingly lower emission measure, albeit the quality of the fit is slightly poorer for a one temperature model. The corona therfore is better described by the photospheric sub-solar composition, but the indications are sparse; we note that a similarly good fit can be obtained with solar metallicity and two, however poorly constrained, temperature components. We show the X-ray spectrum and the best fit one temperature model in Fig. 3, the derived spectral properties are summarized in Table 1.

From the best fit model we obtain an X-ray luminosity of $L_X = 1.3 \times 10^{28}$ erg/s in the 0.2 – 2.0 keV band, corresponding to a surface flux of log $F_X = 5.1$ erg cm^{-2} s^{-1} and an activity level of log $L_X/L_{bol} = -6.16$, indicating that HR 8799 is despite its youth a rather weakly active star. Since HR 8799 is about an order of magnitude X-ray brighter than the average Sun, the X-ray flux at the position of the closest of the detected planets corresponds to the solar X-ray flux that is received by Saturn. To compare our result with the RASS measurement, we also determine the X-ray luminosity for the ROSAT 0.1 – 2.4 keV band from the spectral model, leading to a value of $L_X = 1.6 \times 10^{28}$ erg/s. The ROSAT X-ray luminosity of $L_X = 1.5 \times 10^{28}$ erg/s, obtained from a hardness dependent energy conversion factor, is basically the same as the one obtained with *Chandra* more than 25 years later, pointing to the presence of long-term stable X-ray emission.

4. Summary and conclusions

1. We have detected soft X-ray emission from the extraordinary A5/F0 V star HR 8799. The derived X-ray luminosity

of about $L_X = 1.3 \times 10^{28}$ erg/s in the $0.2 - 2.0$ keV band corresponds to an activity level of log $L_X/L_{bol} \approx -6.2$, pointing to a weakly active star.

2. The ACIS data confirms the ROSAT detection, significantly improves the positional accuracy and additionally enables a deeper study of the X-ray properties of HR 8799. We find that its X-ray emitting coronal plasma has an average temperature of about 3.0 MK, typical for a star with a rather low activity level. Minor X-ray brightness variations are present in our observation; the accompanying spectral changes point to variable magnetic activity.

3. Overall, the X-ray properties of HR 8799 resemble those of mildly active late A/early F stars, rather than those of mid/late A-type stars. Keeping in mind that the attributed spectral type for HR 8799 depends on the classification criterion, the one based on hydrogen lines (F0) most suitable reflects its X-ray properties.

References

Arnaud, K. A. 1996, in ASP Conf. Ser. 101: Astronomical Data Analysis Software and Systems V, ed. G. H. Jacoby & J. Barnes, 17

Bohlender, D. A. & Landstreet, J. D. 1990, MNRAS, 247, 606

Gray, R. O. & Kaye, A. B. 1999, AJ, 118, 2993

Grevesse, N. & Sauval, A. J. 1998, Space Science Reviews, 85, 161

Hünsch, M., Schmitt, J. H. M. M., & Voges, W. 1998, A&AS, 132, 155

Kaye, A. B. & Strassmeier, K. G. 1998, MNRAS, 294, L35

Lowrance, P. J., Becklin, E. E., Schneider, G., et al. 2005, AJ, 130, 1845

Marois, C., Macintosh, B., Barman, T., et al. 2008, Science, 322, 1348

Robrade, J. & Schmitt, J. H. M. M. 2009, A&A, 497, 511

Sadakane, K. & Nishida, M. 1986, PASP, 98, 685

Schmitt, J. H. M. M. 1997, A&A, 318, 215

Schmitt, J. H. M. M., Golub, L., Harnden, Jr., F. R., et al. 1985, ApJ, 290, 307

Simon, T., Ayres, T. R., Redfield, S., & Linsky, J. L. 2002, ApJ, 579, 800

Zuckerman, B. & Song, I. 2004, ApJ, 603, 738